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External chloride stress corrosion cracking: Phenomenon and protection

After carbon steel, stainless steel remains the most commonly used material in the petrochemicals and oil and gas industries. Its long range of chemical resistance against corrosion has made it the first choice for owners/users. With an extended family of grades, stainless steel is resistant to many other damage mechanisms, as well. The variation of grades within austenitic stainless steel is appreciable, with each grade specified for special exposure. Significant runs of piping and equipment onsite made from stainless-steel material handle the most business-critical process service and serve as the lifeline to the least business-critical utility. Resistant to many damage mechanisms, stainless steel out in the open or under insulation is prone to a very delicate kind of stress corrosion cracking known as external chloride stress corrosion cracking (ECSCC).

ECSCC occurs in austenitic stainless-steel material in the presence of an aqueous chloride environment, tensile stress and temperature under insulation. When examining corrosion under insulation (CUI) for stainless-steel materials, ECSCC becomes more relevant. The cracking pattern of ECSCC is typically transgranular and highly branched with a spider-web appearance, as shown in **FIG. 1.** Factors leading to external stress corrosion cracking include type of stainless steel, presence of chlorides, stress temperature and insulating material. The greatest susceptibility to ECSCC is exhibited by austenitic stainless steels with a nickel content of 8% (300 series: SS-304, SS-316, etc.). Greater resistance to ECSCC is generally shown by alloys of either lower or higher nickel contents. Moreover, duplex stainless steel is more resistant, and nickel-based alloys are highly resistant to ECSCC.

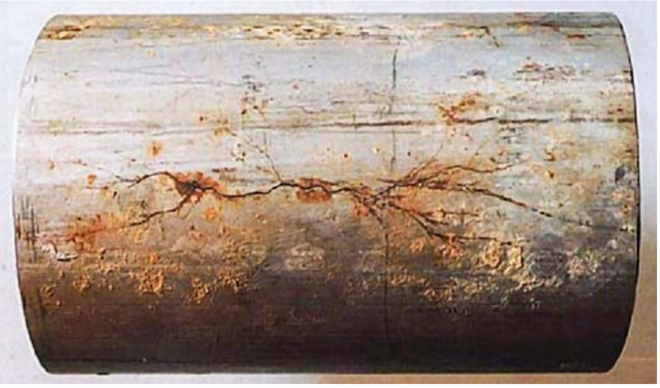

FIG. 1. ECSCC on austenitic stainless steel.

Origins and development. No definitive amount of chlorides presence triggers cracking, as the risk of their concentration always exists. Stress may be of an applied nature; however, the presence of residual stress may also initiate cracking. The critical temperature where cracking begins is typically 60°C (140°F), but cracking can also occur at lower temperatures. ECSCC may occur during in-service or shutdown periods, if chloride-containing solutions are present, at an operating temperature range of 50°C–150°C (122°F–302°F). Heating and/or cooling intermittently into this range will also present an opportunity for ECSCC to develop.

Looking at the piping runs and equipment within a site, it can easily be seen that a major percentage of stainless-steel piping is covered by insulation. Heat conservation is important—or not, depending on a case-by-case basis—but insulation can also be used for personnel protection. Instrument tubing that may not be contributing to heat conservation are also protected by insulation, and an inspection plan may not exist to determine what is happening to them under insulation while in operation. When covering stainless-steel piping, equipment and other components (e.g., tubing) with insulation, ECSCC is the anticipated damage mechanism that is difficult to detect. Typical damage due to ECSCC often goes unnoticed until the insulation is removed or a leak occurs. This is how significant protection against this damage is for all austenitic stainless-steel piping.

To identify which stainless-steel piping system is more prone to ECSCC in a running site, it is recommended to evaluate the likelihood rating for all insulated systems. However, before beginning this evaluation, it is more helpful to identify those systems where insulation is not mandatory as a process requirement. Personnel protective insulation can be replaced with shields, as shown in **FIG. 2.**

Likelihood rating. To calculate the likelihood rating, it is important to know the critical factors that directly or indirectly affect the probability of having ECSCC. Those factors include:

- Operating temperature
- Coating
- Insulation condition
- Heat tracing

- External environment
- Insulation type
- Line size.

TABLE 1 helps calculate the parameter rating for each piping system based upon the assigned score. Based on the seven parameters listed, a score must be assigned to each of them; the sum of the individual scores for each parameter would be a representative figure indicating the likelihood rating, as in **TABLE 2.**

Some parameters can be scored easily based on the data available in associated documentation;[1,2,3,4] however, other parameters exist that require focused attention and field visits, including insulation condition and heat tracing. A complete survey must be planned to determine the actual condition of insulation and to assign a score. Data corresponding to coating may also require some planning to confirm actual coating type and condition. It is recommended to partially strip insulation over austenitic stainless-steel piping to inspect the coating systems applied. For piping systems working under cyclic temperature conditions, the range corresponding to the most critical temperature reached is taken. Those piping systems may have sweating issues, and this also applies to piping systems under cold temperature services.

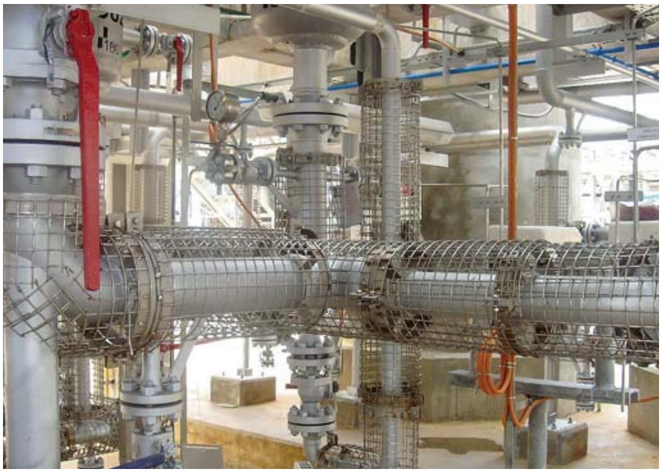

FIG. 2. Thermal shield replacing personnel protective insulation.

In **TABLE 2,** the likelihood rating of E indicates the highest probability of failure.

Once the likelihood rating is defined, it is optional to associate this rating with the consequence rating; this can be done according to the site-based risk rating practices. This can help define inspection plans for piping systems' first failure that pose serious threats to safety, the environment and the business.

The next step is to link the piping systems to the appropriate inspection and maintenance strategy based on their likelihood rating. With the likelihood rating set at high, it is recommended that 100% of the insulation is removed after a full inspection. With the likelihood rating at low, only critical points should be inspected where external sources have greater impact. For all inspections, visual aids supported with dye penetrant testing or eddy current testing are considered as the minimum

TABLE 1. Parameter rating

Parameter	0	1	3	5
Operating temperature		47°C–60°C	121°C–204°C	60°C–121°C
Coating	Quality coating within 8 yr	Quality coating within 15 yr	General coating 8 yr–15 yr	General coating > 15 yr, or unknown age
Insulation type	Insulating coating	Expanded perlite, foam glass, closed-cell foam	Fiberglass, perlite, mineral fiber; insulation has < 10 ppm Cl	Calcium silicate, mineral fiber with > 10 ppm Cl, or unknown
Insulation condition	No deficiencies	Average condition with good maintenance (sealed, no gaps, CML ports with plugs)	Average condition with some deficiencies	Damaged condition with several deficiencies
Heat tracing	None	High-integrity steam system or electric tracing (Cl-free covering)	Steam system with medium integrity	Steam system with visible leaks or electrical with PVC covering
External environment	No sweating	Arid and inland	All other locations	Coastal and marine, cooling tower overspray or external water source exposure (deluge systems, dripping steam condensate)
Line size	Equipment	> 6 in.	> 2 in.–6 in.	≤ 2 in
Location proximity to cooling tower drift	External surface not wetted by cooling tower drift	External surfaces wetted by cooling tower drift infrequently	External surfaces wetted by cooling tower drift occasionally depending on wind direction or seasonal effects	Surfaces wetted by cooling tower drift majority of time
Piping dead leg	Piping section with more than 50% average flow while piping system is operating	Piping section with no flow or limited flow less than 25% of operating time	Piping section with no flow or limited flow more than 50% of operating time	Piping section with no flow at all times during operation

requirement to identify this cracking phenomenon. Guidelines are recommended in **TABLE 3.**

Prevention methods. Aluminum foil is often used as the best prevention method for ECSCC. Plants that do not utilize this method beginning in the commissioning process can install aluminum foil during inspections. It is important to note that the application of aluminum foil costs 60%–80% of the total cost of conventional coating applications. However, a practical limitation of aluminum foil installation exists in sweating conditions, as its life becomes shortened. In those conditions, the application of thermal spray aluminum is recommended. Both aluminum foil and thermal spray act as sacrificial anodes to provide electrochemical protection against ECSCC. Prior to the application of aluminum foil or thermal spray coating, it is essential to wash the metal surface with demineralized water to ensure the surface is free from any chloride contamination.

ECSCC cannot be detected with any regular inspection technique while the affected austenitic stainless-steel piping systems or equipment are in operation. ECSCC can only be determined once it has actually caused damage. Therefore, piping systems and equipment operating in those zones and conditions susceptible to ECSCC should be identified and protected using aluminum foil or thermal spray aluminum. HP

LITERATURE CITED

[1] American Petroleum Institute, "API RP 583: Corrosion under insulation fireproofing," 2014.

[2] National Association of Corrosion Engineers, "NACE SP0198-2010: Control of corrosion under thermal insulation and fireproofing materials," 2010.

[3] American Petroleum Institute, "API RP 581: Risk-based inspection methodology," 2019.

[4] American Petroleum Institute, "API RP 571: Damage mechanisms affecting fixed equipment in the refining industry," 2016.

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TABLE 2. Likelihood rating

Parameter rating total	< 7	7 to < 14	14–17	> 20–27	> 27
Likelihood rating	A	B	C	D	E
	Negligible	Low	Medium	Medium-high	High

TABLE 3. Inspection and maintenance strategy

Likelihood rating	High	High-medium	Medium	Low	Negligible
Insulation removal	100%	40%	20%	All critical points	None
Inspections	Visual + dye penetrant or ECT/ACFM*				None

*ACFM (Alternating current field measurement)

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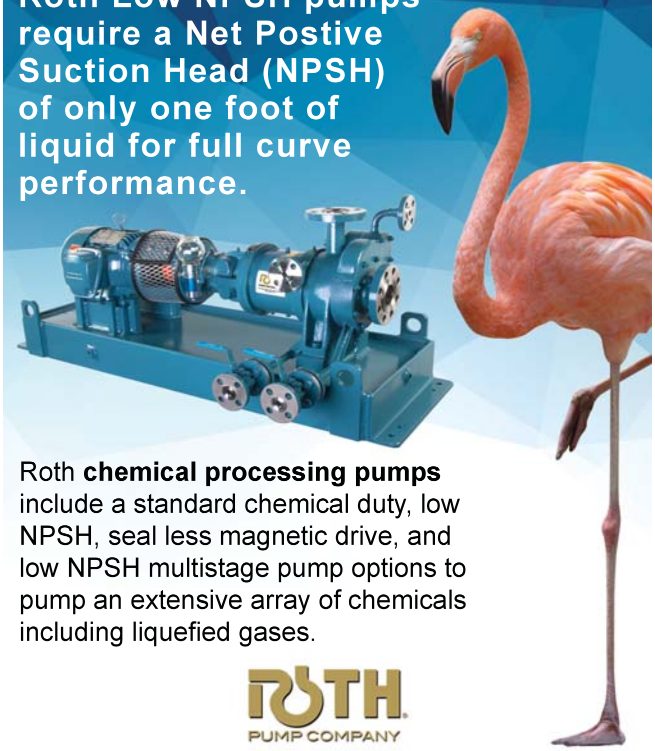

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